Controlled Propulsion of Nanopropellers

Ambarish Ghosh[1,3] and Peer Fischer[1,2,*]

[1]Rowland Institute at Harvard, Harvard University, Cambridge, Massachusetts 02142, USA
[2]Fraunhofer IPM, Fraunhofer Institute for Physical Measurement Techn., Freiburg, Germany
[3]Dept. of Electrical Communication Eng., Indian Institute of Science, Bangalore, India

* *peer.fischer@ipm.fraunhofer.de*

Abtract—**There is currently much interest in controlled motion of micro-/nano-bots that may navigate fluids and tissue, so that they can ultimately deliver chemicals or aid medical diagnosis and therapy. This necessarily entails symmetry breaking to enable locomotion in low-Reynolds number fluid environments. Whether a bottom-up or top-down engineering approach is used, chiral symmetries play a special role from molecules to micron length-scales and naturally facilitate directed diffusion and propulsion. A vacuum shadow-growth method (glancing angle deposition, GLAD) permits the fabrication of chiral colloidal nanopropellers that can be moved through solution with micron-level precision and full position control. The colloids can be produced in large numbers and are right- or left-handed glass propellers which are the size of a bacterial cell and are driven by a homogeneous magnetic field at the top speed of a bacterium (speeds of ~20 body lengths per second). The propellers exhibit a thrust of ~pN and can be chemically functionalized.**

For externally controlled propulsion in liquids it is advantageous to actuate motion with homogeneous magnetic fields, as this permits operation from a distance, and is effective in electrolytes, biological tissues, as well as optically opaque environments. The swimmers should be small enough to navigate confines and to maximize sedimentation times. We describe a fabrication scheme that we have recently realized [1] and that permits large numbers of colloidal swimmers to be made with bio-compatible materials. It is based on “GLAD”, or “glancing angle deposition”, a physical vapor deposition method where the incident vapor flux is incident at extreme grazing angles on a substrate [2]. By manipulating the substrate during the deposition and in combination with geometric shadowing, a wide variety of nano-structured surface morphologies can be obtained. The general method of fabricating chiral helical propellers is to rotate the substrate azimuthally with a fixed tilt at an extreme grazing angle (>85 degree) with a modest angular speed [2].

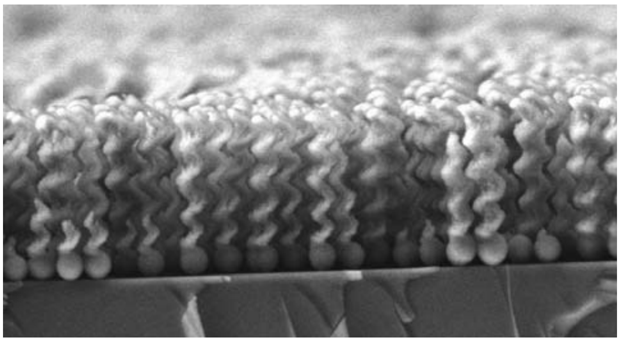

Fig. 1: Wafer section (side-on) of GLAD deposited glass (SiO_2) nano-propellers. Densities exceed tens of billions/wafer.

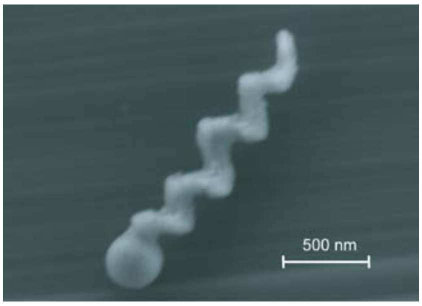

Fig. 2: Individual nanopropeller.

The observed helical pitch is typically given by the ratio of the deposition rate (Angstrom/second) to the angular speed (radian/second). In order to obtain large numbers of identical helical nanopropellers, the substrate is seeded prior to the deposition. This involves the fabrication of arrays of relatively ordered seeds on the substrate prior to the GLAD process. The size and shape of the seeds is critical in determining the morphology of the resultant nano-structures. The typical thickness of the nano-helices is well below 1 micron, which requires wafer arrays of billions of highly uniform sub-micron seeds. This is non-trivial, and a cheap and convenient seeding method will be described.

The subsequent step in the fabrication of the nano-propellers is to render them ferro-magnetic. A high remanent magnetization ensures the propellers can be rotated in small magnetic field strengths. At the same time, the coercivity needs to be high enough that the magnetization is not rewritten. Details regarding the magnetization, chemical functionalization, and labeling with a fluorophore will be given. Potential improvements will also be described.

To drive and observe the propellers a tri-axial Helmholtz coil is arranged around a microscope objective, each coil axis driven by a current amplifier (see Fig. 4). A schematic that shows how the tracks are encoded and experimentally observed repeat tracks with finer and finer detail are given in Fig. 3. We believe that these nanopropellers are the smallest controlled swimmers with the best control that has been realized thus far.

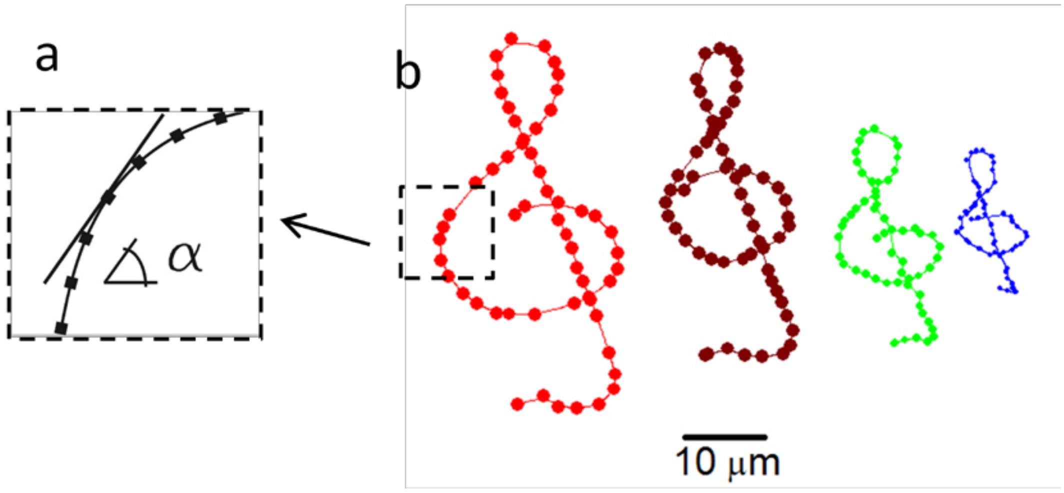

Fig. 3: a) Track of the nanopropellers is linearized and each segment corresponds to a rotation of the magnetic field in a plane orthogonal to the direction of propagation. b) Experimental tracks of the symbol G-clef with increasingly finer control (left to right), observed with fluorescently labeled nanopropellers.

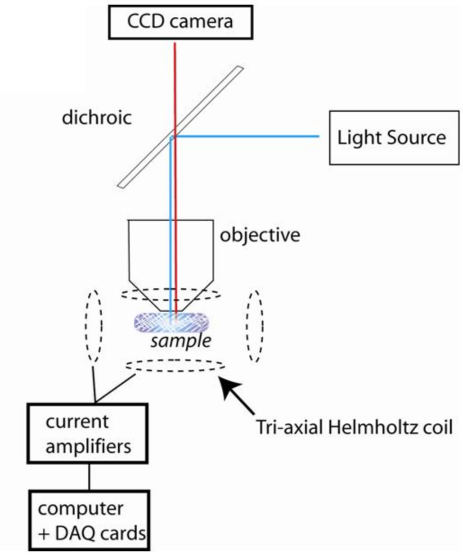

Fig.4: Schematic of the experimental setup used to observe the nanopropellers.

Fascinating engineering questions, such as how to control swarms of swimmers as well as the *in situ* detection of the nanopropellers remain to be addressed and will be discussed.

Acknowledgments – We thank The Rowland Institute for financial support. This work was performed in part at the Harvard Center for Nanoscale Systems (CNS), supported by the National Science Foundation.

References

[1] A. Ghosh; P. Fischer, *Nano Lett*. **9** (2009) 2243-2245.
[2] M.J. Brett, M.M. Hawkeye, *Science* ***319*** (2008) 1192-1193.